PB-230 521

EDUCATION OF ENGINEERS FOR WASTEWATER TREATMENT PLANT OPERATION

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4 November 1969

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PB 230 521

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by

John F. Andrews

A Publication of

The Environmental Systems Engineering Department

Clemson University

Clemson, South Carolina

Presented at

A Workshop on Education Systems for Operators of Water Pollution Control Facilities

Sponsored by the Federal Water Pollution Control Administration Southeast Region

Atlanta, Georgia

November 4, 1969

EDUCATION OF ENGINEERS FOR WASTEWATER TREATMENT PLANT OPERATION

John F. Andrews[1]

INTRODUCTION

The need for skilled operation of wastewater treatment plants is frequently greater than that for industrial processes because of the large temporal variations in wastewater flow and composition. However, most wastewater treatment plants are in a primitive state with respect to process operation when compared with industrial processes. Gross failures, such as the bulking of activated sludge and "sour" anaerobic digesters, are all too frequent. Many other operational problems have been reported; for example, Michel, et al (1) in a study of 1,500 performance audits, lists 499 reported instances of plant bypassing from such causes as stormwater and infiltration, shutdowns for routine maintenance, and mechanical failure. There are significant variations in treatment plant efficiency, not only from one plant to another, but also from day to day and hour to hour in the same plant. Daily variations from 60 to 95 percent efficiency in B.O.D. removal are not uncommon.

Maintenance of plant efficiency nearer the maximum by improved operation (Figure 1) could result in significant decreases in the pollutional

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load placed on our water resources. For example, consider a plant with a maximum B.O.D. removal efficiency of 95 percent, a variation in efficiency of 80 to 95 percent, and an average of 87.5 percent. If, through better operation, plant efficiency could be maintained between 90 and 95 percent with an average of 92.5 percent, the B.O.D. load to the receiving waters would be reduced by 40 percent without increasing the maximum efficiency of the plant. Actual reductions may even be greater than this as demonstrated in the work reported by West (2) in which the average B.O.D. discharge from a 21 M.G.D. activated sludge plant was reduced from 40 to 9 mg/l by improved operation. This represents a reduction in B.O.D. load on the receiving waters of 78 percent!

Another significant advantage of good operation can be improved productivity (3) through an increase in the amount of waste that can be treated per unit of plant capacity (Figure 2). There have been several reported instances where operators have been able to significantly increase the capacity of their plants above the design capacity through changes in operational procedure. For example, Gould (4) was able to double the capacity of his aeration basins for the activated sludge process by introducing the raw waste at intervals along the length of the basins. This idea has since been adopted by designers and is now accepted as a valuable modification of the activated sludge process. Another outstanding example of increased productivity is the work of Torpey (5) on anaerobic digestion in which he was able to triple the loading on his digesters by thickening the sludge prior to its introduction into the digester. This also is now standard practice in many wastewater treatment plants.

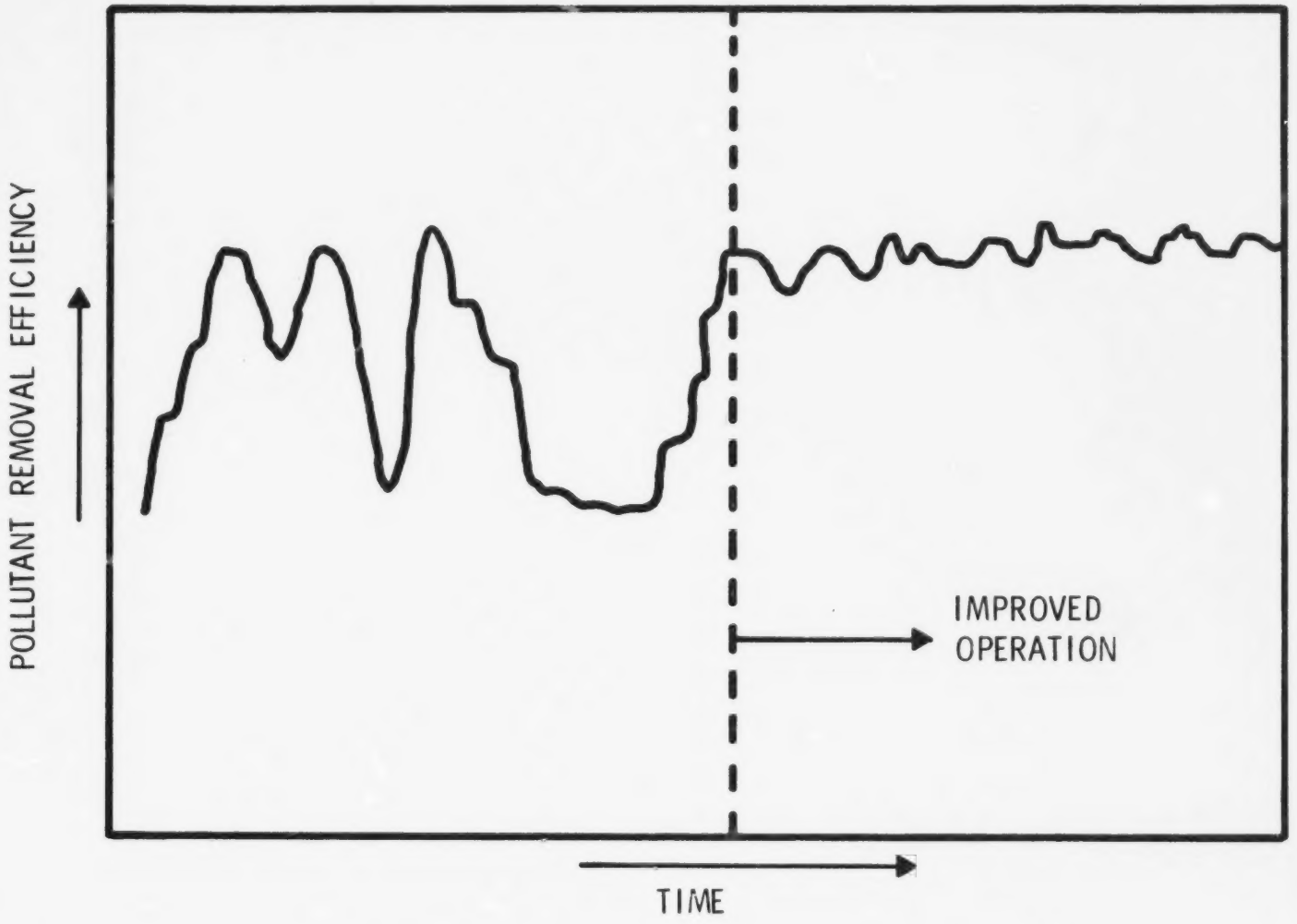

FIGURE 1. VARIATION IN EFFICIENCY CAN BE REDUCED BY IMPROVED OPERATION

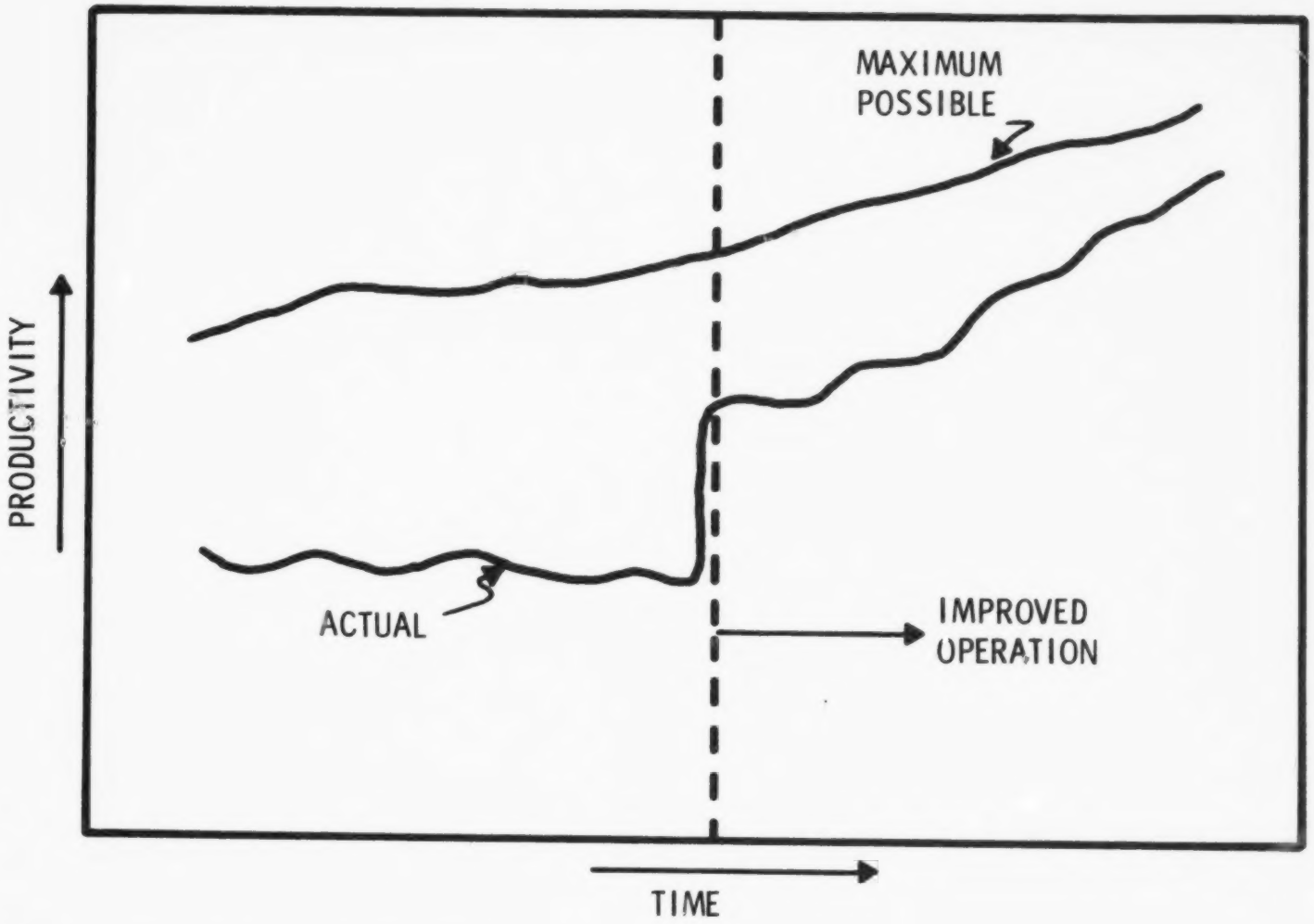

FIGURE 2. PRODUCTIVITY CAN BE INCREASED BY IMPROVED OPERATION

Improved operation can be attained by increasing the quantity and quality of personnel involved and/or by using modern control systems similar to those currently used in industry. The need for an increase in the quantity and quality of personnel is well known and has been summarized in Senate Document No. 49 (6). The prospect of improving plant operation through the use of modern control systems is not as well recognized. Much of the work in this area has been more concerned with the replacement of personnel through automation as, for example, in the automation of the backwashing of rapid sand filters in water treatment plants. In the author's opinion, the improvement of product quality which can be obtained by proper control is equal to or greater in significance than any reduction in labor costs which may be obtained. In fact, the better control systems may require the same or greater labor costs because of the greater need for instrument maintenance and higher quality operating personnel. Perhaps of even more significance is the fact that human labor is being upgraded to do more meaningful tasks.

This paper will be concerned with both the control systems which may be used in plant operation and the educational needs of engineers responsible for plant operation. It should be recognized that the more advanced control systems which will be discussed have yet to be installed in wastewater treatment plants and engineers with the required knowledge to operate plants using these systems have yet to be graduated.

EVOLUTION OF PROCESS CONTROL

Much of the material presented in this section has been taken from Lee, Adams, and Gaines (7) and is gratefully acknowledged. A detailed discussion of all possible control systems is beyond the scope of this

paper; however, a sufficient range will be covered to illustrate the trend in process control. Specific examples, as applied to wastewater treatment plant operation, are presented whenever possible.

Manual Control

In this type of control (Figure 3), the operator uses his senses to determine the status of the process or measure the quality of the product. Any deviations from the desired operating conditions are corrected by changing those variables which can be controlled. The operator then observes if the correction is adequate and continues to make adjustments until the process is operating properly. The operator is the feedback to control the process and good operation is therefore an art which is dependent on the skill and intuition of the operator.

The control of many of our wastewater treatment plants has not advanced much beyond this stage today. Specific examples of variables which are still manually controlled in many plants are:

1. Sludge removal from anaerobic digesters. The operator determines when sludge is properly digested and ready for withdrawal by observing color, texture, and odor of the sludge.

2. Residual chlorine. Residual chlorine is determined using a visual comparator. The operator then adjusts the chlorine feed rate to establish the desired residual.

3. Activated sludge recycle. The return sludge recycle rate is manually adjusted by the operator to maintain a constant concentration of solids in the aeration tank.

Indicating and Recording Instruments

The first portion of the feedback loop to be mechanized was the sensing function. Human senses are replaced with indicating instruments (Figure 4) and automatic recording instruments are added to give a historical record and indicate trends. However, these instruments serve only as an aid

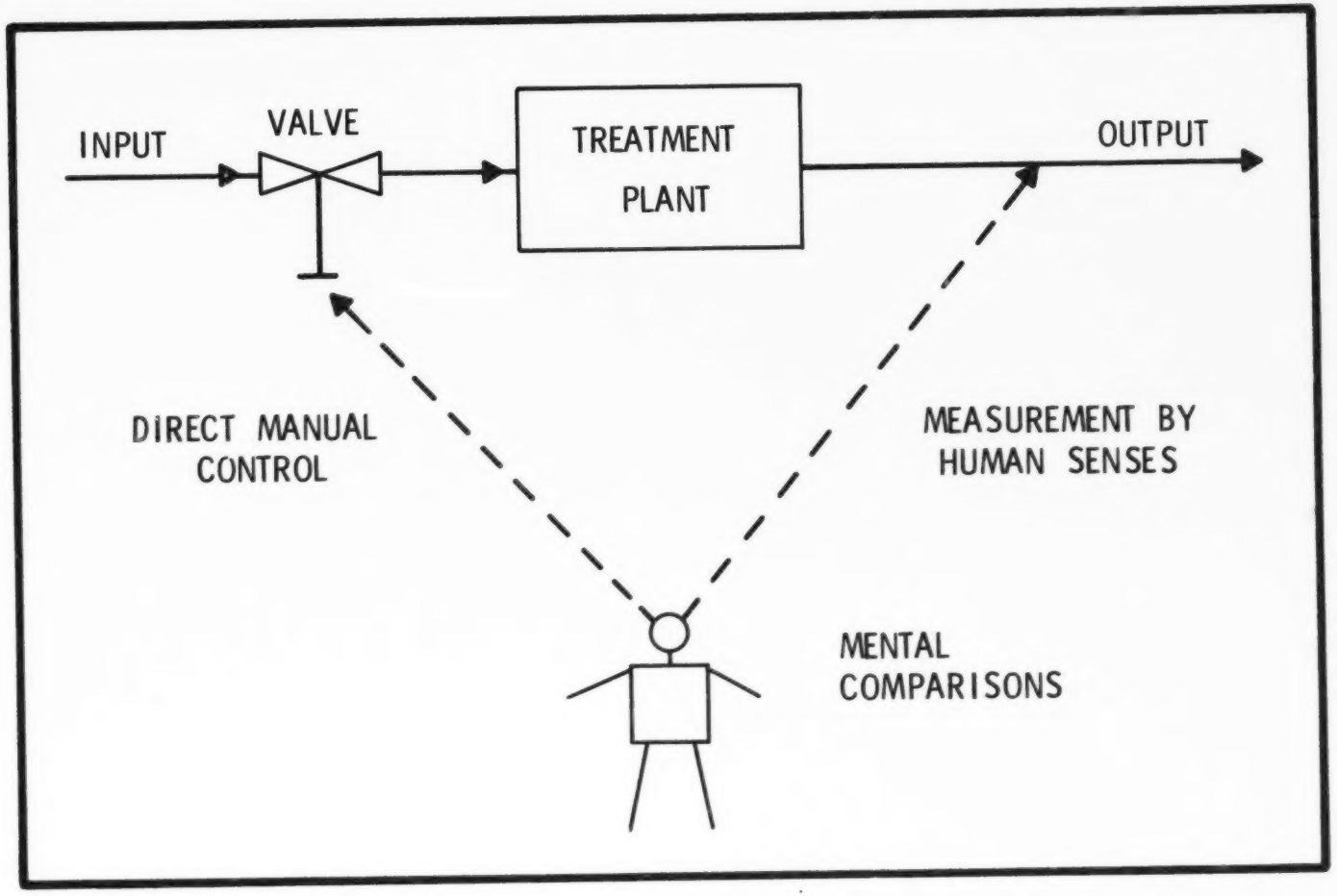

FIGURE 3. MANUAL PLANT OPERATION (after Lee, et. al.[7])

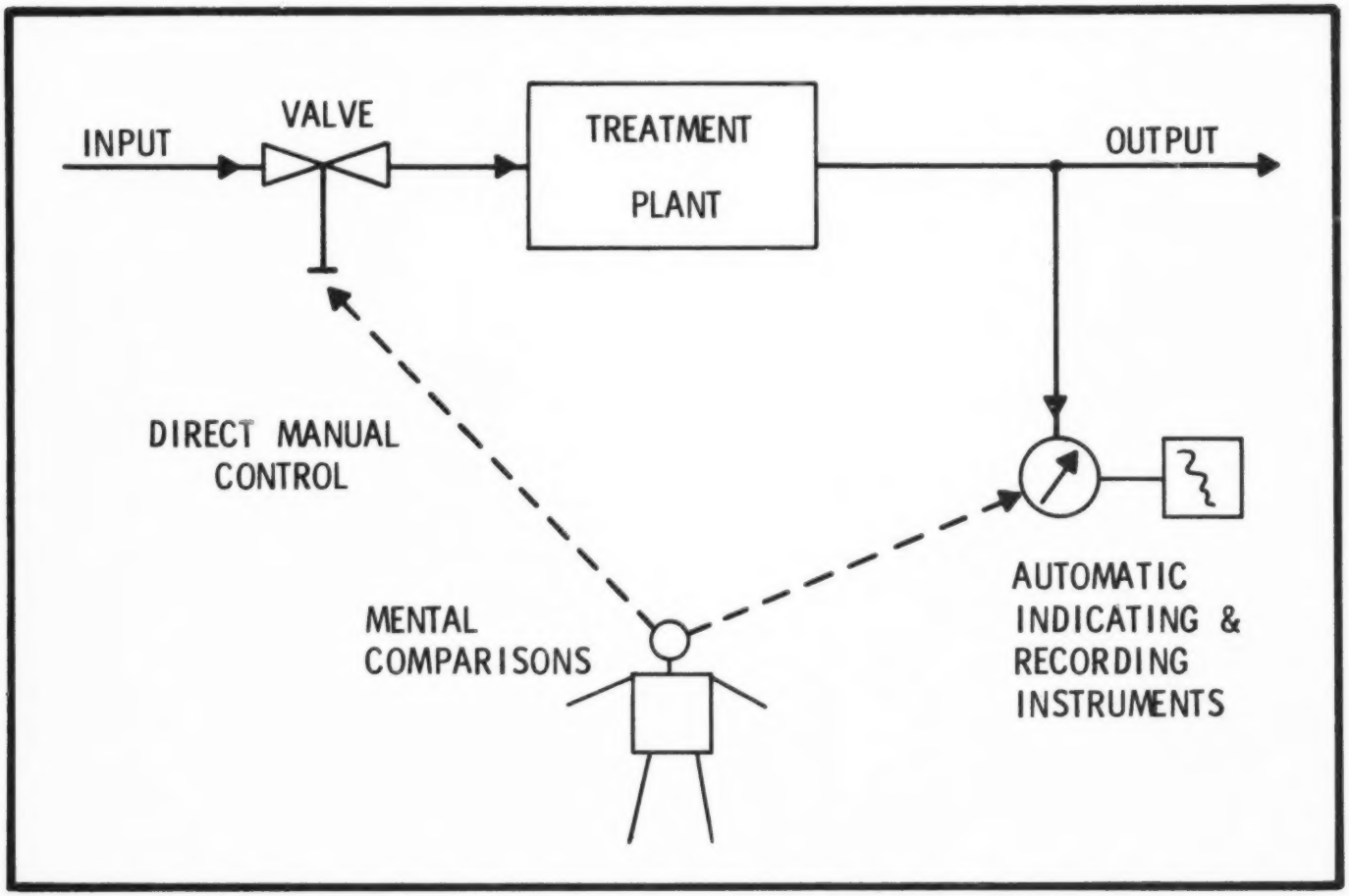

FIGURE 4. INDICATING AND RECORDING INSTRUMENTS ADDED TO PLANT OPERATION (after Lee, et. al.[7])

to the operator and it is still necessary for him to use judgment in detecting error and making the necessary corrections. Examples of indicating and recording instruments currently used in wastewater treatment plants are:

1. Flow and pressure.
2. Residual chlorine.
3. Dissolved oxygen.

Instruments for sensing are a very important segment of the feedback loop. Dependable and accurate instruments are available for many physical measurements such as pressure, temperature, and flow rate. Unfortunately, instruments for most of the biological measurements, many of the chemical measurements, and some of the physical measurements needed for wastewater treatment plant control are still in the development stage, thereby restricting the application of control systems.

Local Automatic Control.

The next stage in the development of control came with the advent of the automatic controller (Figure 5) which removed the operator from continuous participation in the feedback loop. With these controllers it is possible to select values (set points) for the important process variables and have these variables automatically maintained close to their set points. The controller performs the functions of sensing and correcting deviations from the desired operating conditions. However, the operator continues to participate in the feedback loop on an intermittent basis since he must select controller set points in the light of his judgment and experience. Examples of the use of local automatic control in wastewater treatment plant operation are:

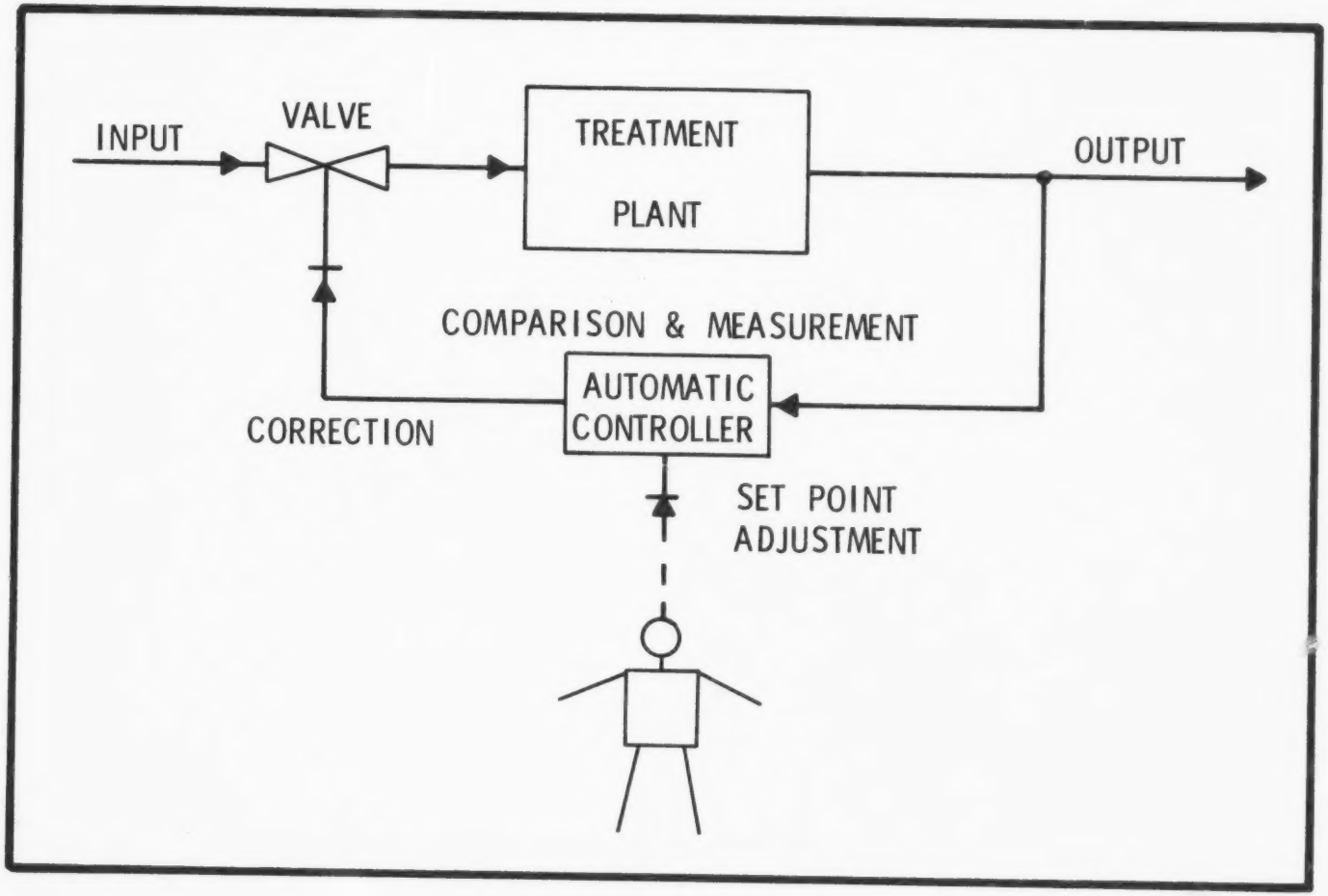

FIGURE 5. OPERATION BY LOCAL AUTOMATIC CONTROLLERS (after Lee, et. al.[7])

1. Effluent chlorination. The controller is set to maintain a specified value of residual chlorine in the plant effluent.

2. Sludge density. The controller is adjusted so that the density of sludge pumped to the anaerobic digester will be maintained above a certain level.

3. Recycle rate. The hydraulic loading to a process, a trickling filter for example, can be maintained constant by controlling a recycle pump according to the raw waste flow rate.

Problems encountered with local automatic controllers are determination of the proper set points and lack of consideration of interactions between variables, i.e., changing the air flow rate to the aeration basin may influence more than just the dissolved oxygen level in the aeration basin.

Centralized Automatic Control

Local automatic controllers are physically located near the process variables to be controlled. As the number of these increases, their maintenance and the monitoring and adjustment of set points becomes more difficult. The solution to this was the development of a centralized control room (Figure 6) where the controllers are brought together and mounted on a control panel. Graphic panels are usually used to display the key variables on a schematic flow diagram of the plant. This assists the operator in organizing and assimilating data and permits him to more quickly grasp the significance of changes in variables and take required corrective action.

Some of the wastewater treatment plants in use today have centralized control rooms with graphic display panels. Typical variables displayed and controlled are pump recycle rates, air flow rates, and residual chlorine concentrations. However, many of the items displayed on these panels are not automatically controlled, but instead require manual action by the operator.

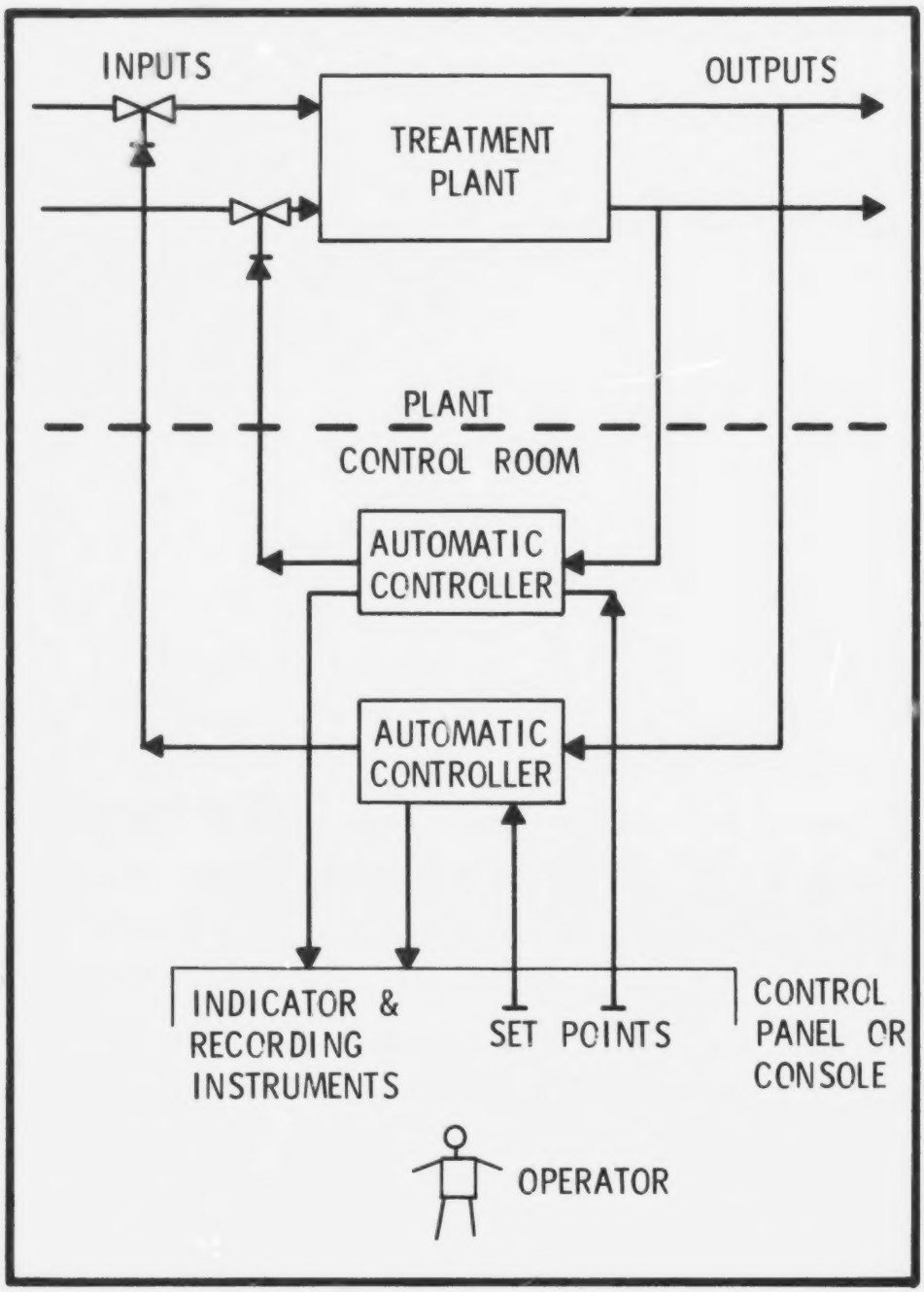

FIGURE 6. PLANT OPERATION BY CENTRALIZED AUTOMATIC CONTROLLERS (after Lee, et. al[7])

Computer Process Control

The digital computer first became available for plant operation in 1958. By 1968 there were more than 700 computers in use for the control of industrial processes in the United States and it is estimated that this number will double by 1971 (8). Computers are now being considered for the control of wastewater treatment plants; and in July of 1969, Siemnes (9) announced that their process control computer would be used in the wastewater treatment plant for Stockholm, Sweden. Only a brief discussion of computer control can be presented in this paper; for a detailed discussion of such systems, the reader is referred to the excellent books of Lee, et al (6) and Savas (10).

The use of computers for process control can range from data processing and monitoring up to some form of optimal control and only these two types of computer control will be discussed in this paper. Most existing computer control systems are somewhere in between these two types. Prospective users should also recognize that although the potential use of computer control is very great, the adaptation of a process to computer control is a difficult and time consuming task. Considerable developmental work will be required for the application of computer control to wastewater treatment plants since these processes are complex and their dynamic behaviour is poorly understood. Bailey (11) has discussed some of the problems which have been encountered in adapting industrial processes to computer control.

Data Processing and Monitoring. Computer control can be installed in stages, and the first step is usually data processing and monitoring (Figure 7). The computer collects data, processes it into a more meaningful form, and displays it to the operator. The operator then adjusts the set points of his automatic controllers. In this mode of operation, the operator is still in

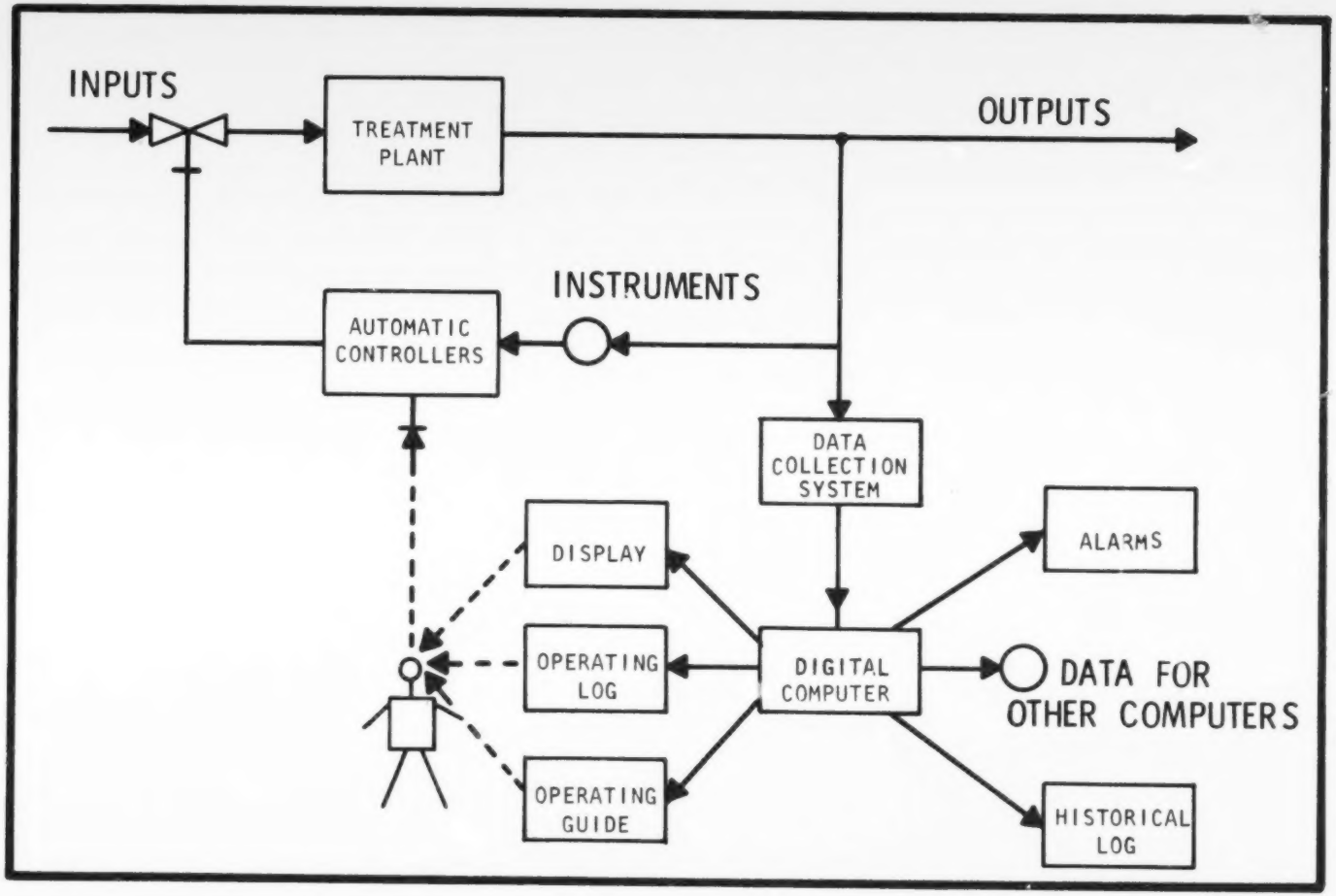

FIGURE 7. DATA PROCESSING AND MONITORING BY DIGITAL COMPUTER (after Lee, et. al.[7])

the feedback loop and the computer only serves to assist him in running the plant. The computer does not take any direct control action. Typical functions which may be performed by the computer are:

1. Scan process sensing instruments, check for instrument malfunction, and convert raw data to meaningful engineering units.

2. Process data into a more meaningful form for the operator by smoothing, curve fitting, integration, differentation, and statistical analysis.

3. Monitor and report on the status of process equipment. For example, the computer can monitor the on-off condition of pumps, valves, motors, and compressors. It can check for overheating of bearings and excessive vibration of motors and compressors.

4. Compare process variables against high-low limits and sound alarms.

5. Prepare an operating log and display information to the operator. This can be in a tabular form, a plotted trend chart of a particular variable, or a tabular or graphical display on a cathode-ray-tube.

6. Furnish the operator with an operating guide upon request, such as instructions in case of an upset, or set points to be used to improve process operation.

7. Furnish data for other computers or provide reduced operating data to higher management.

Guarino and Radziul (12) have reported on the use of a digital computer for processing of the data from wastewater treatment plants in Philadelphia. At the present time data is entered manually; however, they plan to eventually place all of their treatment plants under direct computer control.

Optimal Control. Although this degree of control has yet to be reached in most installations, it is a goal toward which most users are striving. In this type of control (Figure 8) the computer takes over the operation of the plant and controls it so that the overall operation is optimum. It is necessary to tell the computer what is meant by "optimum." For example,

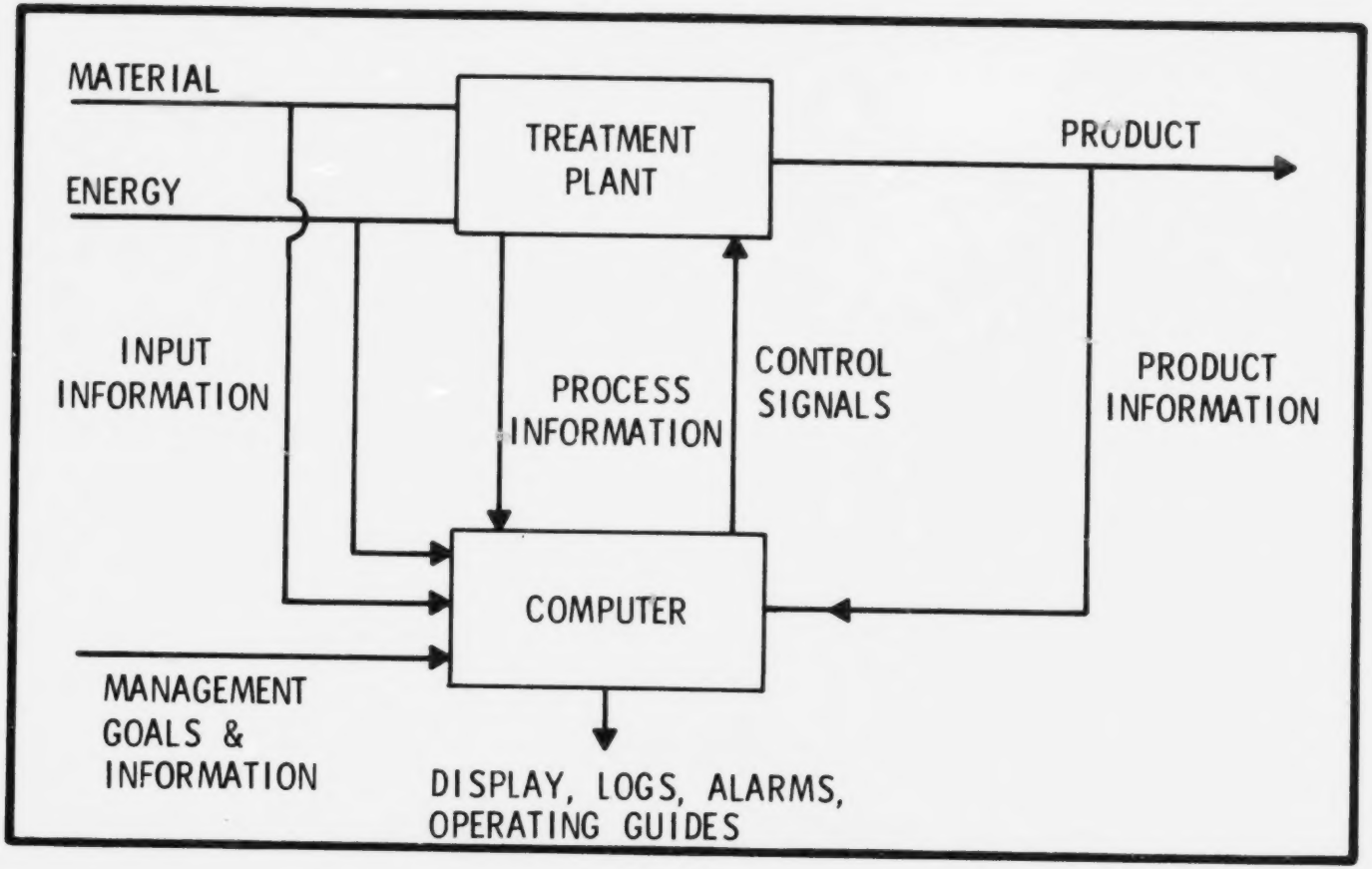

FIGURE 8. A COMPUTER CONTROLLED TREATMENT PLANT (after Savas[10])

in a wastewater treatment plant "optimum" might mean to control the plant at minimum operating cost but with the constraint that the effluent B.O.D. always be equal to or less than 20 mg/l. The computer would take into account all significant process variables and calculate the process conditions and process control changes necessary to obtain optimum performance. It would then initiate these changes.

The automatic controllers can be eliminated with the computer furnishing the signal to manipulate the process variables. This is called direct digital control (DDC) and, for processes where a large number of variables must be controlled, can result in considerable savings in capital costs for instrumentation. Feedforward control, using a dynamic mathematical model stored in the computer, can be incorporated to take control action before process upsets occur. Information for feedforward control is obtained by measuring the inputs to the plant. Some feedback control, utilizing information from the plant outputs, is usually incorporated since the mathematical models used are seldom perfect. Feedback control acts only after a deviation from the desired value has occurred; feedforward control prevents the deviation from occurring.

Little knowledge of the process is required for feedback control; however, considerable time may elapse after the control action is initiated before the process is restored to the proper operating condition. This can have a detrimental effect on the process effluent. Although this disadvantage can be overcome by using feedforward control, considerable knowledge of the process is required to develop the necessary dynamic mathematical model. The first control programs for wastewater treatment plants will have to incorporate a considerable amount of feedback control until their dynamic behaviour is more clearly defined.

PROPOSED EDUCATIONAL PROGRAM

There will always be a need for a man in the control loop either on a continuous or an intermittent basis. The best example of this is the recent landing on the moon where, even with the most sophisticated control system possible, it was necessary for a man to break into the loop for the final landing.

As Brown and Okun (13) have pointed out, the type of control system selected must be suited to the environment in which the plant will be operated. Use of a complex control system would be nonsensical where proper instrument maintenance is unavailable or qualified operators cannot be obtained. It is essential that the qualifications of the men who will operate the plant be considered in selecting a control system. The more advanced control systems which have been discussed are only applicable to those plants where graduate engineers with the proper educational background will be in charge.

There is a need for this type of engineer at almost every level of operation. Industry, and the larger cities such as Los Angeles, Chicago, and Philadelphia, among others, have led the way by employing graduate engineers in plant operations. Rademacher (14) has discussed the great need of governmental agencies for engineers specializing in operations. Consulting firms also need more engineers of this type, not only for the design of control systems, but also to assist in plant start-up and in the preparation of operation and maintenance manuals.

Operation vs. Design

Many environmental engineering programs have stressed either design or design-oriented research and have neglected plant operations. In

addition, most designs have been based on the average inputs or at best, maximum and minimum inputs and have not directly considered that inputs to the plant are highly variable with respect to time. These variations are the primary reason why control is needed and they must be considered in design as well as in operation. Future programs should strike a better balance between design and operation and need to consider the inputs as functions of time. Some of the factors which should be considered in obtaining this balance are:

1. Operating personnel. The need for operation must be minimized through design when it is anticipated that plants will be operated by unskilled personnel. One way in which this is frequently done is by using oversized units to damp out the effects of fluctuating inputs. Oversizing, and therefore capital costs, can be reduced for those plants where qualified operating personnel will be provided.

2. Process stability. It is well recognized that some processes used for wastewater treatment are more stable than others and therefore require less attention to operation. Although this is of considerable importance, quantitative comparisons of the stability of different processes are not available. For example, most environmental engineers will accept the statement that the trickling filter is more stable than the activated sludge process but would be hard pressed to express this in a quantitative fashion.

3. Availability of space. Sizes of units can usually be decreased by increasing the operational effort involved. The best example of this is the manner in which the sizes of spacecraft have been kept to a minimum through the use of sophisticated control systems. Decreases in sizes of plants through improved operation would be of importance in our larger cities where space is at a premium.

4. Reliability. The effects on the receiving waters of failure to obtain the desired degree of treatment either continuously or intermittently must also be considered. A higher degree of reliability will be required for a plant discharging into a stream with no excess assimilative capacity than for one discharging into a stream with considerable excess assimilative capacity. Additional reliability can be obtained through either design or improved operation.

5. Financial. The balance between design and operation is influenced by the feasibility of investing in capital costs or operation and maintenance costs. Industry usually favors investments in

operation and maintenance over capital costs because of taxes. Municipalities have usually preferred investments in capital costs over operation and maintenance since bond issues have been easier to obtain than increases in operating revenue. It is the author's belief that an increase in the ratio of operating and maintenance costs to capital costs would result in better overall wastewater treatment for municipalities.

6. Flexibility. Another reason why industry favors investments in operation and maintenance over capital costs is the flexibility provided in decision making with respect to time. Capital can then be used to modify plants as technological advances occur. On a shorter time scale, it is conceivable that wastewater treatment plants may be operated at variable efficiencies with respect to time in order to match the assimilative capacities of receiving bodies of water. Good operation would be essential in order to obtain this flexibility in efficiency of treatment.

Many of our current wastewater treatment plants have been designed to minimize the need for operation. Although this is an excellent policy for those plants which do not have good operation, it can penalize those where skilled operators are available. For example, even in most of the larger activated sludge processes, there are only three possible controls which the operator may use; namely (a) return sludge flow rate, (b) sludge wasting rate, and (c) air flow rate. The intelligent operator could use much more flexibility than this and on occasion has modified the operation in order to obtain more control. Gould (4), for example, was able to improve operation of his plant by varying the amount and point of introduction of raw waste along the length of the aeration basin. This additional control feature has since been incorporated into several new designs.

Proposed Curriculum

Since the first degree in environmental engineering is the master's degree, the following discussion will be concerned only with curricula for M.S. students specializing in process operations. A typical curriculum is shown in Table I. The actual curriculum would differ somewhat for

TABLE I

TYPICAL CURRICULUM FOR AN M.S. STUDENT SPECIALIZING IN PROCESS OPERATION

Course	Semester Hours
Fall Semester	
Analytical Chemistry	2
Physical Chemistry	2
Organic and Biological Chemistry	2
Microbiology	2
Unit Operations of Sanitary Engineering	3
Systems Engineering I	2
	13
Spring Semester	
Systems Engineering II	2
Unit Processes of Sanitary Engineering	3
Unit Operations & Processes Laboratory	2
Analog, Digital & Hybrid Computations	3
Elective	3
	13
Summer	
Water & Waste Treatment Systems	3
Special Problem	4
	7
Total	33

each student because of differences in background and objectives. It is assumed that the students pursuing this course of study would be recent engineering graduates who have had courses in statistics and computer programming in their undergraduate curricula. Students who have not had such courses could enroll in the program during the summer and take courses in these areas or gain this knowledge through self study prior to enrollment.

The chemistry and microbiology courses would be similar to those currently given in most environmental engineering programs but with more emphasis on automated methods of analysis. As previously mentioned, instruments for sensing are a very important segment of control systems. Chemistry and microbiology, along with the usual mathematics and physics of an engineering graduate, are essential in assisting the student in understanding how a process functions so that he can improve upon design or operation.

The unit operations and processes sequence would emphasize both design and operation of those units most commonly used in water and wastewater treatment. Commonality would be stressed; for example, the basic principles of biological oxidation and reactor engineering are common to the activated sludge process, the trickling filter process, and the anaerobic digester. The response of the units to variable inputs would be studied since this is of prime importance in operation. Control of individual units would be discussed and the factors which should be considered in obtaining a proper balance between design and operation would be examined. A laboratory is necessary so that the student may learn to operate pilot units and take, analyze, and present data in reports. Extensive use would be made of the computer for the solution of design and operational

problems. Student motivation in using the computer would be enhanced by using real engineering problems instead of mathematical exercises.

The portion of the curriculum which differs most widely from existing programs is that block of courses which stress the systems engineering approach. Three of these courses, systems engineering I and II, and analog, digital and hybrid computations, would be taught outside the department by specialists in these areas. In these courses the students would learn the fundamentals of mathematical modeling, block diagramming, simulation, control systems, optimization, and other important tools of systems analysis. An important part of the computations course would be the "hands-on" use of analog and digital computers which are used for process control. The application of these tools to the design and operation of water and wastewater treatment systems would then be covered by environmental engineering professors in a later course. In this course the student would incorporate the operations and processes previously studied into a complete treatment system considering interactions between units, transient behaviour, plant control, and the economics of treatment.

The final course in the proposed program of study would be a special problem selected by the student in consultation with his faculty advisor. The problem could be concerned with the design and/or operation of a particular unit operation or process or some aspect of an entire treatment system. The problem could involve experimental work on a pilot plant, a field installation, or could be a paper and pencil study using data from a field installation. A professional engineer, currently involved in design and/or operation, would be asked to serve on the student's committee to assist in injecting realism into the problem.

The attention devoted to the M.S. curriculum is not meant to imply that Ph.D. study could not be conducted in plant operations. On the

contrary, the author has several Ph.D. students doing research in such areas as dynamic modeling and control of the anaerobic digestion process, stability of the activated sludge process, and computer control of wastewater treatment plants. It has been the author's experience that this type of research is more difficult, from both a theoretical and experimental point of view, than the usual scientific or design-oriented research.

ECONOMICS OF IMPROVED OPERATION

The question may be raised that the use of sophisticated control systems or the hiring of graduate engineers for plant operation would be uneconomical. The author contends that BOD loads to receiving waters can be reduced by improved operation at a cost per pound of BOD removed which is equal to or less than that currently being expended for conventional wastewater treatment. An economic analysis has been made for a 100 M.G.D. activated sludge plant (capital cost of $22,000,000) with the results presented in Table II. The total cost of B.O.D. removed is 5.1 ¢ per pound. If it is assumed that the average efficiency of B.O.D. removal can be increased from 87.5 to 92.5 per cent by improved operation, then at this same cost of 5.1 ¢ for each extra pound of B.O.D. removed, we could afford an additional investment of $154,000 per year for operation and maintenance or we could invest an additional $2,200,000 of capital in a control system. Since a good computer control system can be obtained for $400,000 to $600,000 (10,16) and M.S. level graduate engineers can be hired for $12,000 to $15,000 per year, it can be seen that improved operation is economically justifiable. The economic calculations presented should be conservative. In many plants it may be possible to

TABLE II

ECONOMIC ANALYSIS
100 MGD ACTIVATED SLUDGE PLANT

Capital Cost	$22,000,000
Debt Service	4.3¢/1000 gal.
Operation & Maintenance	3.1¢/1000 gal.
Total Treatment Cost	7.4¢/1000 gal.

Assume average efficiency of B.O.D. removal is 87.5% for an input B.O.D. of 200 mg/l

B.O.D. removed per 1000 gal.	1.46 lb.
Total treatment cost/lb. of B.O.D. removed	5.07¢/lb.

Assume average efficiency of B.O.D. removal is increased to 92.5% by improved operation

Additional B.O.D. removed per 1000 gal.	0.0834 lb.
Value of additional B.O.D. removed at 5.07¢/lb.	0.4234¢/1000 gal.

Additional investment that would be justified

Increase in operation and maintenance budget for higher operator salaries, increased training effort, more personnel, etc.	$154,000/year
or	
Extra capital investment in control system	$2,200,000

Cost data from Smith (15). Adjusted to June, 1969, USPHS Sewage Treatment Cost Index. Interest rate at 5% with 25 year amortization and maturation period for bonds.

increase the average efficiency of B.O.D. removal to more than 92.5 per cent. Improved operation should result in decreased utility costs and operating supplies costs. Improved productivity in the amount of waste that can be treated per unit of plant capacity may be obtained. Relatively small investments in local automatic controllers or centralized automatic control could result in improved efficiency and productivity. The price of computer control systems should decrease with increased use of such systems.

It is of interest to compare investments in controls for the wastewater processing industry with that of the chemical and petroleum industry. Figure 9, from Silva (17), shows the rate at which investment in controls by the chemical and petroleum industry has progressed since 1955. In 1968, the percentage of the total plant cost invested in controls was approximately 12 per cent. This industry apparently feels that additional investment in controls is profitable. For comparison, an investment of $2,200,000 in controls for the 100 M.G.D. activated sludge plant illustrated in Table II would represent 9 per cent of the total plant cost.

The author has been unable to find a tabulation of current investments in controls for wastewater treatment plants. However, Salvatorelli (18) has reported an investment of 4.5 per cent of total plant cost in the monitoring and control system of a specific wastewater treatment plant. Since he considers this monitoring and control system to be the largest and most complete of its type ever constructed, the usual investment in controls for wastewater treatment plants is probably considerably below 4.5 per cent. It would appear that we could afford increased investment in plant operation whether it be in control systems or increased quantity and quality of operating personnel.

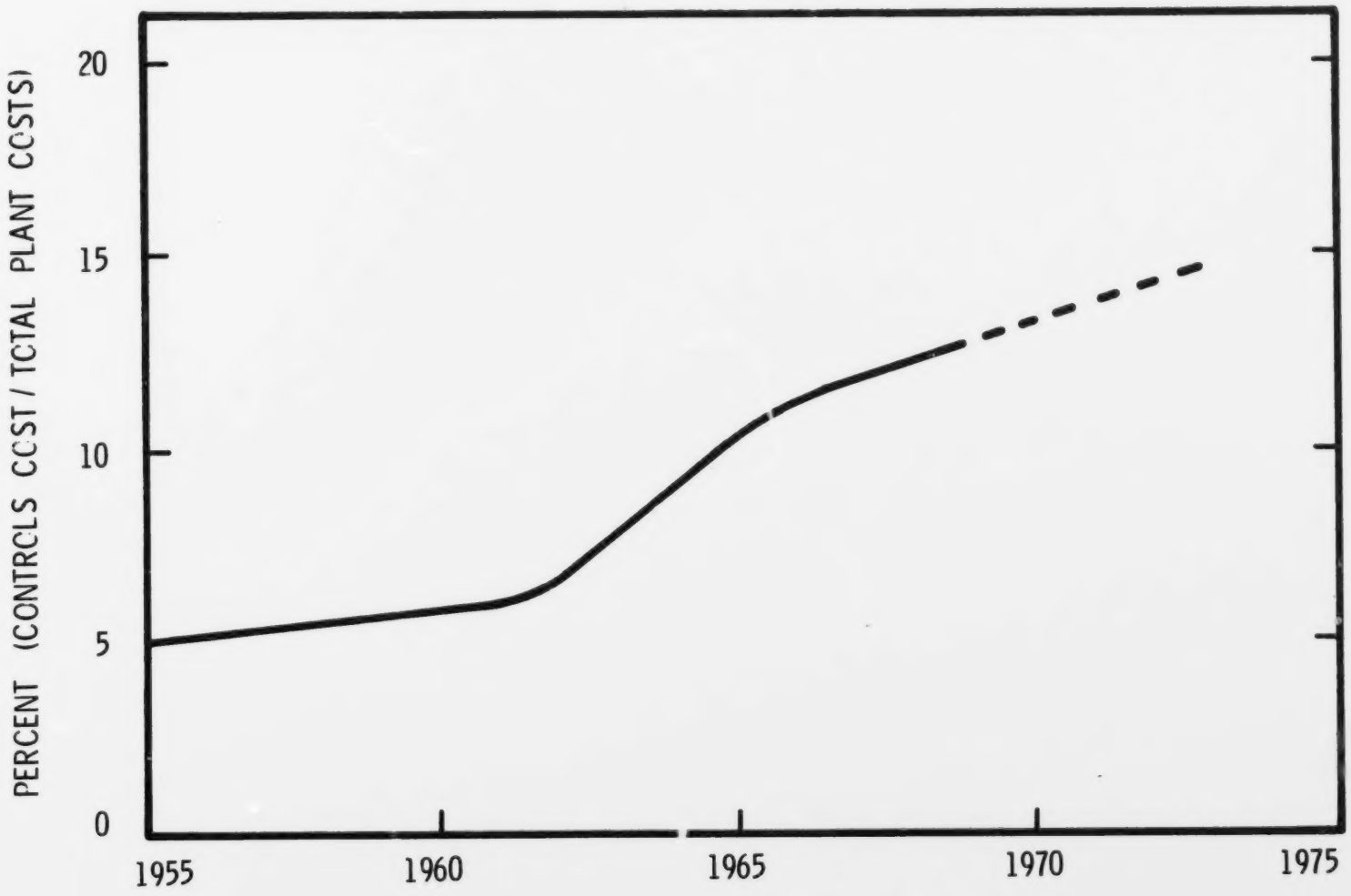

FIGURE 9. CHEMICAL AND PETROLEUM INDUSTRY INVESTMENT IN CONTROLS (after Silva[17])

SUMMARY AND CONCLUSIONS

Wastewater treatment plants require skilled operation because of fluctuations in wastewater flow and composition. However, most plants are in a primitive state with respect to process operation. Improved operation could maintain plant efficiency nearer the maximum and increase plant productivity. It can be obtained by increasing the quantity and quality of personnel involved and/or by using modern control systems.

Control systems used in wastewater treatment plants range from manual control to centralized automatic control. Many of our plants are not far from the manual control stage and could make more use of conventional control systems such as indicating and recording instruments and local automatic controllers. Investigations are now underway on the use of computer process control for wastewater treatment plants. Although the adaptation of these plants to computer control will be a difficult and time consuming task, the rewards can be substantial as demonstrated by the experience of industry.

The type of control system selected must be suited to the operating personnel of the plant. The more complex systems are only applicable to those plants where graduate engineers with the proper educational background will be in charge. In order to produce these engineers, environmental engineering programs in the universities must strike a better balance between design and operation. Automated methods of analysis, transient behaviour, mathematical modeling, simulation, control systems, optimizing techniques, and the "hands-on" use of computers must be considered in the student's courses of study. Students should be given the opportunity to perform research on the operation of existing plants.

Improved operation through the use of modern control systems and the hiring of graduate engineers for plant operation is economically justifiable. Additional BOD removal can be obtained through improved operation at a cost per pount of BOD removed which is less than that currently expended in conventional wastewater treatment plants.

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